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# Exploration and learning strategies in an interactive problem-solving environment at the beginning of higher education studies

Gyöngyvér Molnár*

Institute of Education
University of Szeged
Petofi Sandor sgt. 30-34, Szeged, Hungary

Benő Csapó

MTA-SZTE Research Group on the Development of Competencies
University of Szeged
Petofi Sandor sgt. 30-34, Szeged, Hungary

** Corresponding author*

## Structured Abstract

**Purpose** – Problem solving is a transversal skill that transcends individual disciplines and explores the applicability of knowledge. The purpose of this study was to examine students' learning behaviour in an interactive problem-solving environment by means of a logfile analysis, which provided both a qualitative and quantitative description of the exploration strategies students used in mapping minimally complex, simulated problems.

**Design/methodology/approach** – We propose an approach which enables us to describe not only the quantitative change of students' learning and exploration strategies in a simulated problem-solving environment, but also the qualitative change. The sample for the study was drawn from first-year university students (N=1729; Mean_age=19.58; SD_age=1.8). The MicroDYN approach was employed as a measurement device for creative problem solving (OECD, 2014), which is a specific form of problem solving in interactive situations involving minimal complex systems (Funke, 2014). The assessment took place in the ICT lab of the University of Szeged Library. The test took approximately 45 minutes to complete.

**Originality/value –** The results shed new light and provide a new interpretation of previous analyses of creative problem solving in the MicroDYN approach, since the existing body of empirical research involved analyses of the second (describe) and the third (operate) phases. The true benefit of the latent profile analysis based approach is that it has confirmed our hypothesis that development can be described in terms of not only quantitative change, but also qualitative change. An exclusively quantitative analysis is insufficient, as it would lead to false conclusions in this case.

**Practical implications** – There is great potential in investigating and clustering the problem-solving behaviour and exploration strategy usage of students to learn about their learning strategies in a creative and interactive problem-solving environment. This information has direct implications for teaching, especially for devising instructional

methods for improving students' higher-order reasoning skills and scientific inquiry (Kuhn, 2012).

**Keywords –** technology-based assessment, creative problem solving, exploration strategies, higher education, logfile analyses.

**Paper type:** Academic Research Paper

## 1 Introduction

Technology-based assessment offers new opportunities in educational research. It has bought the possibility of measuring constructs that would be impossible to be measured by other means (e.g. Interactive problem solving) or the opportunity of logging and analysing contextual data, which may contribute to a deeper and better understanding of the examined phenomenon. Traditional methods provide the implementers with very few indicators, such as test scores, while innovative assessment technologies, like logfile analyses can provide answers to research questions which could not be answered previously.

This study focuses on problem solving, especially on interactive problem solving. Problem solving is a transversal skill that transcends individual disciplines and explores the applicability of knowledge. Mapping certain aspects of this skill which had not been investigated previously became a reality with computer-based testing. The purpose of this study was to examine students' learning behaviour in an interactive problem-solving environment by means of a logfile analysis, which provided both a qualitative and quantitative description of the exploration strategies students used in mapping minimally complex, simulated problems.

## 2 Interactive problem solving

"In the past, education was about teaching people something. Now, it's about making sure that students develop a reliable compass and the navigation skills to find their own way through an increasingly uncertain, volatile and ambiguous world." (Schleicher, 2017. p. 3) This shift in the demand resulted in a considerable attention in cross-curricular competencies such as problem-solving skills, which became one of the most extensively studied transversal skills over the last decade (see e.g. OECD 2004, 2014). The development of it became a major objective of educational programmes in several countries. Several definitions have been published (for an overview, see Sternberg, 1994). According to a widely accepted definition of problem-solving skill, it "is an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen." (OECD, 2013. p. 122) According to our interpretation, interactive problem solving is a specific form of problem solving in complex and interactive situations, it is “the ability to explore and identify the structure of (mostly technical) devices in dynamic environments by means of interacting and to reach specific goals” (Greiff and Funke, 2017. p. 95). Interactive problem solving is a 21st-century skill, which is not assessable by traditional assessment methods. It can only be assessed by means of an interactive environment, where information is retrieved not by school knowledge application, but by actively dealing and interacting with the system.

Two approaches are used to measure interactive problem solving: computer-simulated microworlds composed of a huge amount (>1000) of variables in real-life like context (see e.g. “Lohhausen” from Dörner et al., 1983); or artificial and yet complex, but simplistic problems following certain construction rules (e.g. the MicroDYN approach using minimal complex systems from Funke, 1992). In the present study the MicroDYN approach was used, which has several advantages from the assessment’s point of view. It contains the features of a complex system (Funke, 1991) but has low values for these parameters compared to the extremely difficult microworlds. It immensely reduces testing time and gives the possibility to develop scalable problems with regard to their difficulty level. The MicroDYN approach was employed as a measurement device for creative problem solving (OECD, 2014) in the OECD PISA assessment (Funke, 2014).

Interactive problems within the MicroDYN approach contain up to three input and up to three output variables (Greiff et al., 2013) and their relations. In the first phase of the problem-solving process (exploration phase) the participants can freely explore the system by manipulating the input variables and detecting the changes via the output variables according to their actions. The effects, the relations between the input and the output variables can be detected with an adequate problem-solving strategy (Greiff et al., 2012). In the second phase, during the 180 seconds of exploration, problem solvers have to visualise the detected causal relations on a concept map presented on the same screen. In the third phase, problem solvers have to employ the newly mastered knowledge to reach given target values on the output variables by varying the values of the input variables within four steps (duration: max. 180 seconds). The correct concept map is displayed onscreen during to third phase of the problem-solving process to ensure conceptual independence between the two latter MicroDYN phases.

The existing body of empirical research regarding interactive problem solving in MicroDYN approach involved analyses of the second (describe) and third (operate) phases and confirmed the idea that these phases are directly linked to the concepts of knowledge acquisition and knowledge application (Greiff et al., 2013; Wüstenberg et al., 2014).

## 3 Interactive problem-solving exploration strategy: The principle of isolated variation

According to Fischer et al. (2012), VOTAT (vary-one-thing-at-a-time) strategies are the best for identifying causal relations between variables. VOTAT strategies maximise the successful exploration behaviour in minimal complex systems, such as interactive problem solving in the MicroDYN approach, thus in minimal complex systems. By using a VOTAT strategy, students systematically vary at the same time only one input variable, while the others remain unchanged. This way, the effect of the changed variable can be detected in the system by monitoring the changes in the output variables.

The principle of isolated strategy (Müller et al., 2013) is the most obvious and the most systematic VOTAT strategy, when only one input variable is different from the neutral level in each exploration steps and all the other input variables are systematically kept at the neutral level ("0"). This strategy has received attention by solving interactive and minimal complex problems (Wüstenberg et al., 2012).

Using logfile analyses (Greiff et al., 2015), the current paper wishes to address research questions on students' learning behaviour in an interactive problem-solving environment by providing both a qualitative and quantitative description of the exploration strategies students used in mapping minimally complex, simulated problems.

## 4 Aims

The objective of this study is twofold. First, we examine (1) the applicability of the MicroDYN approach for measuring students' interactive problem-solving skills at the beginning of higher education studies. We then examine (2) the effective and less effective exploration and learning strategies in an interactive problem-solving environment using logfile analyses at university level.

## 5 Methods

### *5.1 Participants*

The sample for the study was drawn from first-year university students (N=1729). The students were on average 19.6 years-old (SD_age=1.8). The proportion of boys and girls was about 46 to 54%.

### *5.2 Materials*

In order to analyse students' exploration and learning strategies in interactive environment the MicroDYN approach was applied. A set of six tasks were created with different difficulty levels. The tasks contained up to three input variables and up to three output variables with different fictitious cover stories and fictitious variable names (e.g.

Brekon as name for a specific cat food in the example, see figure 1). For instance, in the task *Cat* (see Figure 1), different kinds of cat food labeled Brekon and Mikas served as input variables, whereas different kind of acting labeled Purring and Movement served as output variables.

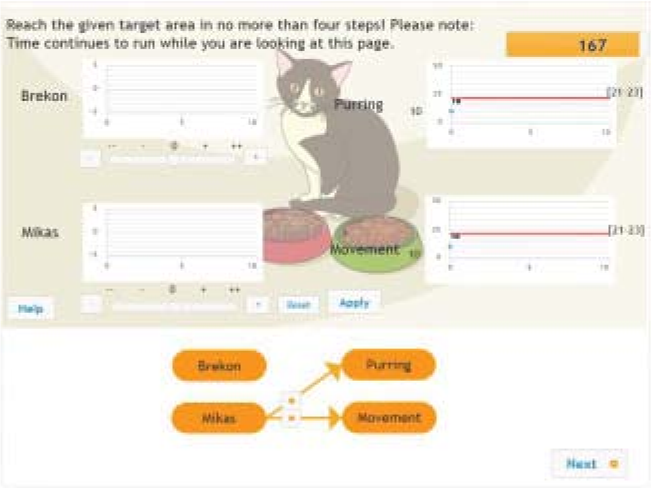



*Figure 1. Screenshot of the MicroDYN task Cat.*

The controllers of the input variables range from "- -" (value=-2) to "++" (value=+2). The current values and the target values of the output variables are displayed numerically (e.g., current value for Purring: 10, target value: 21-23) and graphically (current value: dots; target value: red line). The correct model is shown at the bottom of the figure.

In the first phase of problem solving students had to find out how Brekon and Mikas impact on movement and purring, that is they had to explore the system. In the second phase they had to draw the connections between variables in the concept map onscreen, based on the acquired knowledge in the first phase. In the third phase problem solvers had to change the values of the input variables, Brekon and Mikas to reach the given target area (indicated with a red line) for movement and purring in no more than four steps, that is, by a maximum of four clicks on the application button and within 180 seconds. In this case the right concept map was given onscreen.

### *5.3 Procedures*

The interactive problem-solving test was administered online via the eDia platform, which made it possible to log students' activities during the process of solving test problems, track their behaviour, and identify qualitative developmental differences. At the beginning of the data collection, students were provided with instructions about the usage of the user interface, including a trial task. Subsequently, they had to explore, describe and operate unfamiliar, artificial and fictitious systems with different level of difficulty. This process involves several complex cognitive and noncognitive activities, such as strategic planning, multistep intervention activities, dynamic decision-making, incorporation of feedback from the problem environment, and self-regulation (Greiff et al., 2013). The assessment took place in the ICT lab of the University of Szeged Library. The test took approximately 45 minutes to complete. Students' activity was coded according to the strategy they used and then clustered for comparison. We conducted a latent profile analysis to ascertain the exploration strategies employed by our latent classes as they worked to understand the problems.

### *5.4 Scoring*

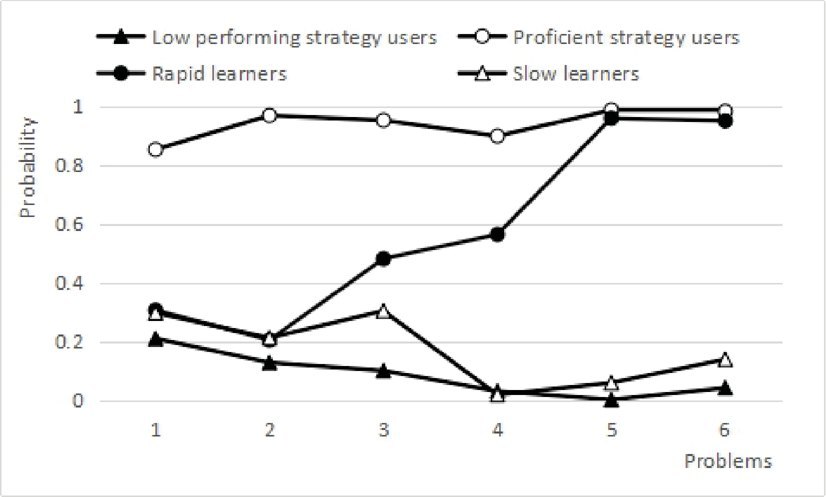
In the first phase of the problem-solving process, students had the opportunity to intervene in the system in an unguided way, apply as many exploration steps as they want to. Using the log data each exploration step was labelled according to the number of the changed variables, the familiarity level of the new settings and the amount of the new information. Then these new labels were scored according to the application level of the principle of isolated variation strategy with 0, 1 and 2. No credit (0 point) was given, if no isolated variation was applied for any of the input variables; 1 credit was given by partial isolated variation, that is, isolated variation strategy was applied for some but not all of the input variables; and 2 points were given in case of the full isolated variation, that is isolated variation strategy was applied for all of the input variables. These scores, representing the qualitatively different classes of students' exploration behaviour built the bases of the latent profile analyses.

Achievement in the second and third phases of the problem-solving process was scored dichotomously. In the second phase, for knowledge acquisition, credit was given ("1") for a completely correct model, where all of the connections between the input and output variables on the concept map were accurately indicated fully matching the underlying problem structure. Otherwise, the response was scored as incorrect ("0"). For knowledge application, students' responses were scored as correct ("1") if students reached the given target values within 180 seconds and at most in four steps; otherwise, the response was scored incorrect ("0").

## 6 Results

The internal consistency of the test based on the traditional scoring methodology, that is focusing only on the success in the second and the third phase of the problem-solving process was high (Cronbach's α=.90). The reliability of the recoded log data based on the exploration behavior of the students in the first phase of the problem-solving process proved to be even higher (Cronbach's α=.97). That is, the interactive problem-solving test and the newly developed methodology about the scoring of students' problem solving and exploration behavior is reliable to measure students' problem-solving and exploration skills in an interactive problem-solving environment, restricted to minimal complex systems.

The effective and less effective exploration and learning strategies in an interactive problem-solving environment was analysed by means of latent profile analyses using the recoded logfile collected during the first phase of the problem-solving process. We hypothesised different latent class profiles on the basis of the extent to which students applied the principle of isolated variation while exploring the interactive problem scenarios. We examined solutions in two to eight classes. Based on our findings (AIC=11745, BIC=12023, aBIC=11861, Entropy=.90, LMR test=300, $p<.001$), distinction can be made between four qualitatively different groups: (1) low-performing strategy users (14.9% of the students); (2) proficient strategy users (62.9%); (3) slow learners (10.9%); and, finally, (4) rapid learners (11.2%), the most valuable group from an educational point of view (Figure 2). No so-called intermediate strategy users were detected.




*Figures 2. Latent class profiles for the proficient explorers (white circles), rapid learners (black circles), slow learners (white triangles), and low-performing explorers (black triangles)*

These analyses yielded important information about different types of students who performed equally well but who used different routes to get there. There were no substantial differences between the low-performing strategy users and the slow learners with regard to their overall problem-solving performance; however, they possess different learning potential. Rapid learners showed a remarkable learning curve while working on the problems. Their exploration strategy and achievement reached the same level as of the proficient explorers during the second half of the assessment, but they were markedly lower during the first half. Because they began on a lower level than the proficient explorers, their overall performance was somewhat below the proficient explorers' level and they seemed to be intermediate explorers based only on their overall performance. The great learning potential these students possess was generally not reflected in their overall performance. The rapid learners might have a set of general cognitive schemata that they can adapt quickly and flexibly to the demands of a specific situation. However, this learning process requires some time to take effect.

## 7 Conclusions

The results shed new light and provide a new interpretation of previous analyses of interactive problem solving (called creative problem solving in the OECD PISA 2012 assessment) in the MicroDYN approach, since the existing body of empirical research involved analyses of the second (describe) and the third (operate) phases. The interactive problem-solving test can be reliable applied on university level to measure students' exploration skills and learning strategies. We detected four qualitatively different exploration and learning profiles by using latent profile analyses. Low-performing and slow learners who usually employed no or partially isolated variation strategy. Rapid learners, the most valuable group from an educational point of view. These students started out as low-performers in their exploration behaviour on the first CPS tasks, showed a rapid learning curve afterwards and by the end of the test, they reached the same high level of exploration behaviour as the proficient explorers. Proficient strategy users employed consistently the optimal isolated variation strategy.

The true benefit of the latent profile analysis-based approach is that it has confirmed our hypothesis that development can be described in terms of not only quantitative change, but also qualitative change. An exclusively quantitative analysis is insufficient, as it would lead to false conclusions in this case.

The practical implication of the study is, that there is great potential in investigating and clustering the problem-solving behavior and exploration strategy usage of students to learn about their learning strategies in a creative and interactive problem-solving environment. This information has direct implications for teaching, especially for devising instructional methods for improving students' higher-order reasoning skills and scientific inquiry (Kuhn, 2012).

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## Appendix: Questionnaire items

| Counter-knowledge |
|---|
| CK1: There is gossip that thrives on lies, exaggerations and partial truths<br>CK2: There are malicious rumours which support mistrust<br>CK3: There are malicious stories about staff that often lead to misunderstandings<br>CK4: Unverified information is shared by technological means<br>Source: Adapted from Chapman and Ferfolja (2001) |
| Knowledge application |
| KA1: My organization has processes for applying knowledge learned from mistakes<br>KA2: My organization has processes for applying knowledge learned from experiences<br>KA3: My organization has processes for using knowledge in the development of new services<br>KA4: My organization has processes for using knowledge to solve problems<br>KA5: My organization matches sources of knowledge to problems and challenges<br>KA6: My organization uses knowledge to improve efficiency<br>KA7: My organization uses knowledge to adjust its strategic direction<br>KA8: My organization is able to locate and apply knowledge to changing competitive conditions<br>KA9: My organization makes knowledge accessible to those who need it<br>KA10: My organization takes advantage of new knowledge<br>KA11: My organization quickly applies knowledge to critical competitive needs<br>Source: Adapted from Gold *et al*. (2001) |
| Organizational Agility |
| OA1: We have the ability to rapidly respond to customers' needs<br>OA2: We have the ability to rapidly adapt production to demand fluctuations<br>OA3: We have the ability to rapidly cope with problems from suppliers<br>OA4: We rapidly implement decisions to face market changes<br>OA5: We continuously search for forms to reinvent or redesign our organization<br>OA6: We see market changes as opportunities for rapid capitalization.<br>Source: adapted from Lu and Ramamurthy (2011) |
| Organizational Memory |
| OM1: It is committed to keep "fresh" everything that has been learned in the development of services.<br>OM2: The causes of failure in service development processes are always analyzed and everything learned in them is shared.<br>OM3: We have specific mechanisms to share what is learned in the service development process.<br>OM: We have formal processes to identify misconceptions in the service development process.<br>Source: Adapted from Chou *et al*. (2007) |